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Functional Properties of Pea Starch, Air-Classified Pea Starch, and Combinations of Pea Starch or Air-Classified Pea Starch and Guar Gum, Locust Bean Gum, Xanthan Gum or Carboxymethyl Cellulose

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List of Abbreviations

ΔH	Endothermic enthalpy of gelatinization
ACPS	Air-classified pea starch
CMC	Carboxymethyl cellulose
db	Dry basis
DSC	Differential scanning calorimetry
FV	Final viscosity
GG	Guar gum
LBG	Locust bean gum
OAC	Oil absorption capacity
PS	Pea starch
PT	Pasting temperature
PV	Pasting viscosity
RS	Resistant starch
SP	Swelling power
Tc	Completion temperature of gelatinization
To	Onset temperature of gelatinization
Tp	Peak temperature of gelatinization
TV	Trough viscosity
WAC	Water absorption capacity
WBC	Water binding capacity
WSI	Water solubility index
w/w	Weight by weight basis
XG	Xanthan gum

EXECUTIVE SUMMARY

Starch molecules can interact with non-starch hydrocolloid molecules, which may alter the functionality of starch during gelatinization, pasting, and/or gel formation and storage. The objective of this study was to determine the effects of several hydrocolloids on the functionality of pea starch and air-classified pea starch. Pea starch, air-classified pea starch, and combinations of pea starch or air-classified pea starch and guar gum, xanthan gum, locust bean gum or carboxymethyl cellulose (each at concentrations of 0.33, 0.66 and 1.00%, w/w) were evaluated with respect to the following physico-chemical characteristics: thermal properties, pasting properties, swelling power, water solubility, freeze-thaw stability, shear stability, water binding capacity, oil absorption capacity and resistant starch concentration.

In general, the presence of hydrocolloids reduced the enthalpy of gelatinization and pasting temperature of pea starch, but increased peak, trough and final viscosities, water solubility, shear stability, and freeze-thaw stability. Hydrocolloids had either no effect or a variable effect on the gelatinization temperature, swelling power, water binding capacity, oil absorption capacity and resistant starch content of pea starch. In most cases where significant effects were observed, the magnitude of the impact was relatively small. For most treatments, the effect of a hydrocolloid at a particular concentration on the functionality of pea starch and air-classified pea starch were not significantly different; however, corresponding treatments with air-classified pea starch and combinations of air-classified pea starch and the hydrocolloids did exhibit lower pasting viscosities, higher water solubility and lower freeze-thaw stability, due to the

lower starch (84% vs. 96%) and higher protein (6% vs. 0.3%) contents of air-classified pea starch. It was concluded that combinations of pea starch or air-classified pea starch and hydrocolloids could mimic some of the functionalities of chemically-modified corn and other commercial starches.

INTRODUCTION

Starch is an homogeneous polymer of glucose comprised of two types of molecules, amylose (primarily linear or straight-chain starch) and amylopectin (branched-chain starch). The physicochemical properties of starches are largely determined by the ratio of these two molecular types and the degree of branching and the molecular weights of the amylose and amylopectin chains. Pea starch, like other pulse starches, has an intermediate amylose concentration (30-35%). Pea starch exhibits a strong gelation capacity (Vose 1977), shear stability (Ratnayake et al 2001), acid stability (Ratnayake et al 2001) and enzyme resistance (Ratnayake et al 2001). However, pea starch also exhibits high syneresis (Ratnayake et al 2001), a relatively high cooking temperature (Yook et al 1994) and a low pasting viscosity (Ratnayake et al 2001). Due in part to these properties, pea starch has seen limited applicability in food systems.

Non-starch hydrocolloids (referred to hereafter as hydrocolloids), such as guar gum, xanthan gum, locust bean gum and carboxymethyl cellulose, are used to modify the structure and texture of both food and non-food systems. Guar gum is a neutral galactomannan consisting of a β-1,4-D-mannose backbone with galactose residues linked to it. Guar gum hydrates completely in cold water (Hoefler 2004). Xanthan gum is

an anionic heterogeneous polymer consisting of a β-linked glucose backbone and side chains of a single unit of glucuronic acid and and two units of mannose (Hoefler 2004). Locust bean gum is a neutral galactomannan, similar to guar gum, except that it contains fewer galactose side units. Locust bean gum does not hydrate completely in cold water and typically requires heating to about 60°C to solubilize completely (Hoefler 2004). Carboxymethyl cellulose is an anionic, synthetic gum derived from cellulose by reacting cellulose with sodium hydroxide and monochloroacetic acid to derivitize hydroxyl groups to carboxymethyl ether groups. Carboxymethyl cellulose exhibits thinning when heated (Hoefler 2004). Starches and hydrocolloids, both independently and in combination, thicken, stabilize and provide texture and viscosity to food products. Some of the negative characteristics of starches (syneresis, retrogradation) can be altered by chemical modification. Alternatively, combinations of starch and hydrocolloids might replace chemically-modified starches in a natural, chemical-free manner.

There have been a number of studies investigating the physicochemical effects of the addition of hydrocolloids to tapioca, corn and wheat starches. It has been reported that the addition of hydrocolloids to starch (wheat, corn, waxy corn) enhanced its gelatinization, pasting and retrogradation properties (Alloncle and Doublier 1991; Alloncle et al 1989; Christianson et al 1981; Fanta and Christianson 1996; Funami et al 2005; Gudmundsson et al 1991; Kim and D'Appolonia 1977). Shi and BeMiller (2002) reported that mung bean starch plus 0.4% (w/w) of carboxymethyl cellulose or xanthan gum exhibited a higher viscosity during pasting than did mung bean starch. The addition of konjac-glucomannan to corn starch improved its water holding capacity, thus

improving the freeze-thaw stability of corn starch gels (Yoshimura et al 1998). The addition of alginate, guar gum or xanthan gum to sweet potato starch improved its freeze-thaw stability; xanthan gum was more effective than guar gum, and both xanthan gum and guar gum were more effective than alginate (Lee et al 2002). Muadklay and Charoenrein (2008) reported that tapioca starch plus 0.25 or 0.50% (w/w) of xanthan gum exhibited lower syneresis after freezing and thawing than did tapioca starch. These authors also reported that tapioca starch plus xanthan gum exhibited lower syneresis values than did tapioca starch plus locust bean gum. Tapioca starch plus guar gum exhibited synersis values that were not significantly different than that of tapioca starch.

The thermal and pasting properties of combinations of hydrocolloids (yellow mustard mucilage, locust bean gum and gelatin) and pea starch have been studied (Liu and Eskin 1998; Liu et al 2006). The addition of yellow mustard mucilage to pea starch increased the peak viscosity and the enthalpy of gelatinization, and decreased the swelling power and solubility, of pea starch (Liu et al 2006). Guar gum and xanthan gum were selected for the current study due to the synergies of these gums when added to other starches at levels up to 0.8%. Locust bean gum was selected to aid in understanding possible interactions with starch molecules. Locust bean gum, like guar gum, is a galactomannan; however, guar gum consists of evenly spaced galactose units, whereas locust bean gum consists of unevenly-spaced galactose side units, on the mannose backbone. The uneven distribution of galactose side units alters the functionality of locust bean gum when compared to guar gum, as the regions of the mannan backbone without galactose substitution can interact with different molecules and alter solubility (Hoefler 2004).

Carboxymethyl cellulose was selected for use in the current study as it is one of the most common hydrocolloids used in the food industry and is typically more soluble than other non-starch hydrocoloids. Typical commercial usage levels of guar gum and locust bean gum in food are 0.35-2.0% and 0.15-0.8%, respectively (BeMiller 2007). Typical commercial usage levels in food of xanthan gum range from 0.1 to 0.5% (Chantaro and Pongsawatmanit 2010). The majority of studies investigating the addition of hydrocolloids to native starches used levels under 1% (w/w). This study utlilized levels of 0.33, 0.66 and 1.00% (w/w). A successful outcome of this project would be to identify combinations of pea starch or air-classified pea starch and hydrocolloids having unique, commercially-relevant functional characteristics with the potential to replace chemically-modified starches in food and non-food applications. Hence, the overall objective of this project was to evaluate the functional behaviour of combinations of pea starch or air-classified pea starch and several hydrocolloids (guar gum, xanthan gum, locust bean gum and carboxymethyl cellulose), specifically their thermal properties, pasting properties, swelling power, water solubility, freeze-thaw stability, shear stability, water binding capacity, oil absorption capacity and resistant starch concentration.

MATERIALS AND METHODS

Pea starch (PS) and air-classified pea starch (ACPS) were provided by Parrheim Foods, Saskatoon, SK. PS and ACPS contained 96 and 84% (db) starch and 0.3 and 6.0% (db) protein, respectively (data provided by Parrheim Foods). The commercial starches

evaluated were low degree of substitution, cross-linked corn and waxy corn starches, a medium degree of substitution, cross-linked waxy corn starch, a high degree of substitution, cross-linked waxy corn starch, and a low degree of substitution, acetylated corn starch. Hydrocolloids [guar gum (GG), xanthan gum (XG), locust bean gum (LBG) and carboxymethyl cellulose (CMC)] were incorporated into pea starch or air-classified pea starch at concentrations of 0.33, 0.66 and 1.00% (w/w). The individual starches and the non-starch hydrocolloid combinations were evaluated for their thermal properties, pasting properties, swelling powers, water solubility indices, freeze-thaw stabilities, shear stabilities, water binding capacities, oil absorption capacities and resistant starch concentrations.

Thermal properties were determined by differential scanning calorimetry (DSC) according to Ratnayake et al (2001) using a sample size of 2.5 mg (db) and 70% total moisture (approximately 9.2 µL of water added to samples depending on their moisture contents). A Rapid Viscoanalyzer (Newport Scientific Ltd., Warriewood, NSW, Australia) was used to determine pasting properties using standard method #2 with an 8% starch slurry at pH 7.0. Swelling powers and water solubility indices were determined according to Li and Yeh (2001). Freeze-thaw stabilities were determined according to Muadklay and Charoenrein (2008) where 6% starch slurries were heated at 95°C for 30 minutes with continuous agitation. The heated paste was cooled to room temperature in a 10°C water bath for 30 minutes to aid nucleation. The samples were then frozen at -18°C for 20 hours. The frozen paste was thawed for 2 hours at 30°C in a water bath,

vortexed for 15 seconds and centrifuged at 1000 x *g* for 20 minutes. The supernatant was decanted and percent syneresis was calculated using:

% syneresis = (weight of water removed/weight of starch paste) x 100

Shear stabilities was performed according to Praznik et al (1999) and calculated using:

$$Shear\ stability = \eta_{after} / \eta_{before} \times 100$$

Water binding capacities were determined by the method of Medcalf and Gilles (1965) at room temperature (approximately 22°C). Oil absorption capacities were analyzed according to Sathe and Salunke (1981). Resistant starch concentrations were determined using the Resistant Starch kit (Megazyme International, Ireland) according to the AACC method 32-40 (2000). Data were analyzed using PROC GLM and differences between means were determined by Least Significant Differences using SAS (SAS Institute Inc., Cary, NC) where n = 4. Comparing specific data to commercially manufactured chemically modified starches was performed using PROC TTEST using SAS (SAS Institute).

RESULTS AND DISCUSSION

Starch functionality is influenced by the botanical source of the starch, the amylose: amylopectin ratio, and the properties of amylose and amylopectin such as molecular weight and the degree of branching (Ratnayake et al 2001). Other substances in food systems, such as fats, sugars, proteins, salts and non-starch polysaccharides, also play a role in the functionality of starch. Compounds in the continuous phase of a starch system will affect starch functionality by altering water availability or by interacting or

binding with starch molecules. Hydrocolloids form molecular networks that may entrap starch granules.

Thermal properties of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC)

Gelatinization is a phenomenon where starch granules undergo an order-disorder transformation when thermal energy is applied and excess water is available (Ratnayake et al 2002). As water migrates into the granule, the granule swells, intermolecular associations among starch granules are disrupted, amylose leaches into the continuous phase, and the crystallinity of the granule is lost (BeMiller and Whistler 1996). The thermal properties of PS, ACPS, and combinations of PS or ACPS and GG, XG, LBG or CMC are presented in Table 1. DSC traces revealed that all combinations of PS or ACPS and the hydrocolloids examined in this study exhibited single endothermic peaks. Similarly, single endothermic peaks were observed with starches from each of yam, taro, sweet potato or yam bean when combined with GG or LBG (Huang et al 2009) and with tapioca starch in combination with XG (Chantaro and Pongsawatmanit 2010). None of the hydrocolloids exhibited a marked effect on the onset temperature of gelatinization (To), the peak temperature of gelatinization (Tp) or the completion temperature (Tc) of gelatinization of PS or ACPS, or the endothermic enthalpy of gelatinization (ΔH) of ACPS. Combinations of PS and the hydrocolloids had lower ΔH than did PS, due in part to the hydrocolloids reducing the amount of water available for

Table 1 Thermal properties of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
PS	61.1 ± 0.7abc	67.5 ± 0.2a	85.5 ± 0.5a	15.3 ± 0.7a
PS + 0.33% GG	60.1 ± 1.0bc	66.5 ± 1.6a	84.9 ± 1.6a	13.1 ± 1.4b
PS + 0.66% GG	61.4 ± 0.2ab	68.0 ± 0.5a	86.3 ± 0.1a	13.2 ± 0.3b
PS + 1.0% GG	62.0 ± 0.0a	68.4 ± 0.0a	85.1 ± 1.0a	11.9 ± 0.7b
PS + 0.33% XG	60.6 ± 0.4ab	67.9 ± 0.4a	86.8 ± 0.7a	12.7 ± 0.0b
PS + 0.66% XG	60.4 ± 0.5ab	67.9 ± 0.1a	86.5 ± 0.7a	13.3 ± 1.1ab
PS + 1.0% XG	60.8 ± 0.2ab	68.1 ± 0.0a	86.7 ± 0.5a	13.4 ± 0.1ab
PS + 0.33% LBG	61.7 ± 0.5ab	68.1 ± 0.4a	84.7 ± 0.5a	11.6 ± 0.1b
PS + 0.66% LBG	61.1 ± 0.5ab	68.1 ± 0.1a	86.7 ± 0.3b	12.8 ± 1.2b
PS + 1.0% LBG	60.7 ± 0.2ab	68.0 ± 0.2a	86.6 ± 0.8b	13.1 ± 0.3b
PS + 0.33% CMC	60.7 ± 0.4ab	68.1 ± 0.2a	87.0 ± 0.1a	12.6 ± 0.5b
PS + 0.66% CMC	60.1 ± 0.7bc	67.2 ± 0.3a	85.7 ± 1.8a	13.5 ± 1.8ab
PS + 1.0% CMC	60.3 ± 0.0ab	67.8 ± 0.2a	85.2 ± 0.5a	12.8 ± 1.8b
ACPS	61.1 ± 0.3a	68.9 ± 0.1c	87.2 ± 0.2a	13.1 ± 0.6a
ACPS + 0.33% GG	61.0 ± 0.3a	68.7 ± 0.2c	86.2 ± 1.9a	12.5 ± 1.4a
ACPS + 0.66% GG	61.4 ± 0.3a	68.8 ± 0.1c	87.0 ± 0.1a	13.7 ± 1.1a
ACPS + 1.0% GG	61.4 ± 0.4a	68.8 ± 0.7c	86.2 ± 0.7a	12.6 ± 0.3a
ACPS + 0.33% XG	61.8 ± 0.7a	70.6 ± 0.2a	88.5 ± 1.1a	13.1 ± 0.8a
ACPS + 0.66% XG	61.9 ± 0.7a	70.4 ± 0.1ac	87.8 ± 0.4a	12.5 ± 0.1a
ACPS + 1.0% XG	61.7 ± 0.9a	70.2 ± 0.7ac	88.0 ± 0.4a	12.5 ± 0.6a
ACPS + 0.33% LBG	61.5 ± 0.1a	68.8 ± 0.4c	86.5 ± 0.1a	12.7 ± 0.8a
ACPS + 0.66% LBG	61.8 ± 0.5a	69.4 ± 1.1bc	87.2 ± 0.8a	12.2 ± 0.7a
ACPS + 1.0% LBG	61.8 ± 0.1a	70.2 ± 0.0ab	88.4 ± 2.1a	12.9 ± 0.9a
ACPS + 0.33% CMC	60.9 ± 0.4a	68.7 ± 0.7c	86.9 ± 0.6a	13.5 ± 0.0a
ACPS + 0.66% CMC	61.1 ± 0.4a	68.9 ± 0.4c	87.8 ± 0.2a	13.3 ± 0.6a
ACPS + 1.0% CMC	61.3 ± 0.2a	68.9 ± 0.2c	86.8 ± 0.2a	12.7 ± 0.4a

* Means followed by the same letter in each column for each starch are not significantly different ($p > 0.05$) by Least Significant Differences. To = onset temperature of gelatinization, Tp = peak temperature of gelatinization, Tc = completion temperature of gelatinization, ΔH = enthalpy of gelatinization.

gelatinization of the crystalline regions of the starch granules (Viturawong et al 2008, Chiaswang and Suphanthanka 2006, Huang et al 2009). The higher protein and fibre content in ACPS may interfere with interactions between starch molecules and hydrocolloids. The ΔH values exhibited by most combinations of PS and the hydrocolloids were comparable ($p<0.05$) to those of a low degree of substitution, cross-linked waxy corn starch, for which ΔH was determined to be 12.1 J/g.

Pasting properties of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC)

Pasting is the heating of starch in an excess of water in the presence of shear, where starch granules swell and exhibit amylose leaching, leading to an increase in viscosity. With continued heating and shearing, the granules disintegrate and both amylose and amylopectin become dispersed in the aqueous phase.

Pasting properties of PS, ACPS, and combinations of PS or ACPS and GG, XG, LBG or CMC are presented in Table 2. In general, the addition of a hydrocolloid reduced the pasting temperature (PT) and increased the peak viscosity (PV), trough viscosity (TV) and final viscosity (FV) of PS. Noteworthy exceptions were observed with CMC where the combination of PS and 0.66% CMC had no significant effect on PT, PV, TV or FV, and 1.0% CMC increased PT and reduced PV, TV and FV. Similar effects were observed for PS with LBG or yellow mustard mucilage (Liu and Eskin 1998), yam, taro, sweet potato or yam bean starch with GG or LBG (Huang et al 2009), waxy corn starch with XG or GG (Achayuthakan et al 2008) and tapioca starch with 0.125 to 1% XG (Pongsawatmanit and Srijunthongsiri 2008; Chantaro and Pongsawatmanit 2010). Glucans and mannans may

Table 2 Pasting properties of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	PT (°C)	PV (cP)	TV (cP)	FV (cP)
PS	73.8 ± 0.2b	1334 ± 93e	1025 ± 93ef	2157 ± 126ef
PS + 0.33% GG	72.5 ± 0.3d	1748 ± 47cd	1331 ± 107bc	2620 ± 105bc
PS + 0.66% GG	72.3 ± 0.3d	1898 ± 70ab	1332 ± 41ab	2716 ± 129ab
PS + 1.0% GG	72.4 ± 0.3d	1953 ± 40a	1369 ± 63a	2764 ± 49ab
PS + 0.33% XG	72.6 ± 0.2d	1666 ± 35d	1142 ± 54cd	2409 ± 96cde
PS + 0.66% XG	72.7 ± 0.2cd	1652 ± 54d	1154 ± 38cd	2350 ± 88de
PS + 1.0% XG	72.8 ± 0.6c	1503 ± 157e	1123 ± 67de	2210 ± 53gf
PS + 0.33% LBG	72.4 ± 0.3d	1713 ± 44cd	1201 ± 60cd	2568 ± 56bc
PS + 0.66% LBG	72.3 ± 0.2d	1823 ± 20abc	1313 ± 35ab	2783 ± 29ab
PS + 1.0% LBG	72.4 ± 0.0c	1888 ± 32a	1315 ± 15ab	2760 ± 41a
PS + 0.33% CMC	72.2 ± 0.4d	1755 ± 38bcd	1234 ± 39bc	2500 ± 51cd
PS + 0.66% CMC	73.8 ± 0.2b	1413 ± 82e	1118 ± 85de	2035 ± 130g
PS + 1.0% CMC	74.7 ± 0.5a	1172 ± 120f	953 ± 73f	1553 ± 80h
ACPS	75.1 ± 0.1cd	724 ± 32bcd	726 ± 29bc	1104 ± 37abc
ACPS + 0.33% GG	73.2 ± 0.2fg	648 ± 32de	510 ± 24d	1105 ± 23abc
ACPS + 0.66% GG	72.4 ± 0.2h	699 ± 18cd	542 ± 23d	1168 ± 32ab
ACPS + 1.0% GG	72.2 ± 0.3h	850 ± 46a	828 ± 57a	1117 ± 75ab
ACPS + 0.33% XG	72.6 ± 0.4gh	716 ± 20bcd	701 ± 21bc	1001 ± 29cd
ACPS + 0.66% XG	72.8 ± 0.4gh	692 ± 4cd	676 ± 4c	962 ± 7d
ACPS + 1.0% XG	74.3 ± 0.1e	732 ± 13bc	725 ± 12bc	1052 ± 10bcd
ACPS + 0.33% LBG	75.2 ± 0.1c	734 ± 4bc	727 ± 6bc	1098 ± 18abc
ACPS + 0.66% LBG	74.4 ± 0.6de	785 ± 8ab	778 ± 6ab	1172 ± 12a
ACPS + 1.0% LBG	72.5 ± 0.6gh	821 ± 35a	811 ± 34a	1175 ± 51a
ACPS + 0.33% CMC	73.9 ± 0.4ea	590 ± 47e	575 ± 45d	826 ± 67e
ACPS + 0.66% CMC	76.1 ± 0.4b	412 ± 40f	401 ± 36e	572 ± 47f
ACPS + 1.0% CMC	77.2 ± 0.4c	394 ± 89f	386 ± 89e	553 ± 12fc

*Means followed by the same letter in each column for each starch are not significantly different ($p > 0.05$) by Least Significant Differences. PT = pasting temperature, PV = peak viscosity, TV = trough viscosity, FV = final viscosity.

interact and form networks that increase paste viscosity. However, anionic hydrocolloids such as CMC may not interact with starch molecules due to molecular dissimilarity in charge and composition. The effects of the hydrocolloids on the PT of ACPS were not significantly different than those seen for PS. In contrast, hydrocolloids tended to have an effect that was not significantly different or reduced PV, TV and FV of ACPS. Noteworthy exceptions were the increases in PV and TV observed for ACPS in combination with 1.0% GG or LBG, and the substantial reductions in PV, TV and FV for ACPS in combination with CMC at all concentrations. Molecular associations between starch molecules from ACPS and galactomannans (GG and LBG) may increase viscosities of ACPS. Protein and fibre present in ACPS may interfere with interactions between starch molecules and galactomannans at lower addition levels of GG or LBG. In all cases, treatments with ACPS exhibited lower PV, TV and FV than corresponding treatments with PS, due to the lower concentration of starch in ACPS.

Earlier viscosity development and, as a result, a lower PT may be due to molecular interactions between the hydrocolloids and leached amylose (Christianson et al 1981; Shi and BeMiller 2002). Interactions between leached starch molecules and hydrocolloid molecules also may increase viscosity (Chaisawang and Suphantharika 2006). The PTs of PS with GG, PS with XG, and PS with LBG were comparable to that of an acetylated waxy rice starch (72.0°C) (Liu et al 1999). Chaisawang and Suphantharika (2006) reported that the PVs of combinations of tapioca starch and 0.35% of GG or XG were higher than that of tapioca starch. These authors published RVA profiles for 0.35% GG and XG alone, and the resulting curve exhibited no peaks or increased viscosity. Shi and BeMiller (2002)

reported that CMC interacted with amylose during the pasting of maize starch. When a mixture of maize starch and 0.4% CMC was heated at 65°C for 3 hours, amylose was distributed throughout the slurry, whereas when maize starch was heated without CMC, the amylose was located at the granule surface or close to the granule. This phenomenon is interesting as the total proportion of amylose in the slurry was comparable for maize starch and the blend of maize starch with 0.4% CMC, indicating that amylose and CMC may interact and lead to earlier development of viscosity.

The PV and FV of PS with 0.33% GG or LBG were comparable to those of a low degree of substitution, cross-linked corn starch, for which PV and TV were determined to be 1769 and 1216 cP, respectively ($p > 0.05$). The PVs of PS with 0.33% GG, 0.33% LBG or 0.33% CMC were comparable to that of cross-linked taro starch (1728 cP), and the PVs of PS with 0.33 or 0.66% XG were comparable to that of cross-linked lotus starch (1632 cP) (Gunaratne and Corke 2007).

Swelling powers and water solubility indices of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC)

Starch granules, when heated in an excess of water, swell and starch molecules (primarily amylose) are leached into the aqueous medium (continuous phase) due to the reduction in hydrogen bonding in the crystalline regions, allowing water to form new hydrogen bonds with the now exposed hydroxyl groups (Ratnayake et al 2002). Swelling power is influenced by amylose-lipid complexes (Hoover and Manual 1996, Tester and Morrison 1990) and amylopectin structure (Tester et al 1993), which will affect the

extent to which starch molecules are leached during heating. The swelling power of pure starch indicates the strength of starch molecular interactions, where high swelling powers indicate weak molecular interactions.

Swelling powers (SPs) and water solubility indices (WSIs) for PS, ACPS, and combinations of PS or ACPS and GG, XG, LBG or CMC are presented in Tables 3 and 4, respectively. Generally, the SPs and WSIs for corresponding combinations of PS or ACPS and hydrocolloids were slightly higher, or not significantly different, than those of PS or ACPS, respectively. Typically, legume starches have relatively low SPs and WSIs due to strong interactions between amylose chains in the amorphous regions of the granule (Hoover et al 2010). Previous research indicated that combinations of starch and hydrocolloids exhibited lower SPs and WSIs than did starch alone, due to increased hydrogen bonding between hydrocolloid molecules and leached amylose (Liu et al 2006, Christianson 1981, Huang et al 2009). This difference in findings between those in the published literature and in this study may be attributable to differences in the method of starch isolation, as the pea starches used in this study would possess higher contents of damaged starch due to the use of dry impact milling in their preparation (Suksomboon and Naivikul 2006). ACPS and combinations of ACPS and hydrocolloids exhibited SPs that were not significantly different, and higher WSIs, than PS and corresponding combinations of PS. The higher WSIs were attributed to the soluble protein content of ACPS.

At 65°C, the swelling powers of PS with 0.33 or 0.66% XG and PS with 0.33, 0.66 or 1% LBG were comparable to that of a low degree of substitution, cross-linked corn

Table 3 Swelling powers (SPs) of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	SP (%) 65°C	SP (%) 75°C	SP (%) 85°C	SP (%) 95°C
PS	7.1 ± 0.1g	11.9 ± 0.9bcde	13.6 ± 1.0d	17.1 ± 0.8cd
PS + 0.33% GG	7.3 ± 0.2bfg	11.1 ± 0.1e	13.7 ± 0.5d	17.3 ± 0.7d
PS + 0.66% GG	7.4 ± 0.1efg	11.9 ± 0.0bcde	13.8 ± 0.3d	17.6 ± 0.8abc
PS + 1.0% GG	7.6 ± 0.0def	11.3 ± 0.6de	14.4 ± 0.2bcd	18.0 ± 0.9abc
PS + 0.33% XG	7.9 ± 0.4cd	11.6 ± 0.3a	14.4 ± 0.0bcd	17.8 ± 0.3ab
PS + 0.66% XG	7.8 ± 0.2d	12.7 ± 0.3a	14.2 ± 0.2cd	18.4 ± 0.4abc
PS + 1.0% XG	8.5 ± 0.4b	13.0 ± 0.1ab	15.3 ± 0.0b	18.6 ± 0.4abc
PS + 0.33% LBG	7.7 ± 0.3def	12.0 ± 0.5bcde	13.9 ± 0.3d	17.2 ± 0.9cd
PS + 0.66% LBG	7.8 ± 0.0b	12.1 ± 0.5bcde	13.9 ± 0.8d	17.5 ± 0.1bc
PS + 1.0% LBG	7.9 ± 0.1cd	11.5 ± 0.2cde	14.1 ± 0.4d	18.7 ± 0.6ab
PS + 0.33% CMC	8.0 ± 0.1cd	12.4 ± 0.3bcd	14.3 ± 0.2cd	18.2 ± 0.2abc
PS + 0.66% CMC	8.3 ± 0.2bc	12.7 ± 0.3abc	15.2 ± 0.2bc	18.4 ± 0.4abc
PS + 1.0% CMC	9.1 ± 0.2a	13.9 ± 1.4a	17.0 ± 0.4a	19.1 ± 0.5a
ACPS	8.5 ± 0.0de	12.0 ± 0.1a	14.1 ± 1.0bcd	17.0 ± 0.9a
ACPS + 0.33% GG	8.8 ± 0.2cde	12.7 ± 0.4a	14.5 ± 0.3abcd	16.1 ± 0.2a
ACPS + 0.66% GG	10.1 ± 0.5ab	12.7 ± 0.2a	15.3 ± 0.5abc	16.7 ± 0.1a
ACPS + 1.0% GG	10.1 ± 0.5ab	12.3 ± 0.3a	15.7 ± 0.7a	16.5 ± 0.8a
ACPS + 0.33% XG	9.5 ± 0.9abc	12.4 ± 0.3a	14.0 ± 0.3cd	17.8 ± 0.8a
ACPS + 0.66% XG	10.2 ± 0.3a	13.4 ± 0.8a	14.7 ± 0.8abcd	17.0 ± 0.4a
ACPS + 1.0% XG	8.5 ± 0.2cde	11.7 ± 0.3a	14.1 ± 0.8bcd	16.0 ± 0.9a
ACPS + 0.33% LBG	7.6 ± 0.0e	11.3 ± 0.1a	13.4 ± 0.2d	16.9 ± 0.3a
ACPS + 0.66% LBG	8.6 ± 0.6cde	12.6 ± 0.1a	13.3 ± 0.1d	16.1 ± 0.0a
ACPS + 1.0% LBG	8.8 ± 1.0cd	11.9 ± 0.5a	13.5 ± 0.2d	16.1 ± 0.6a
ACPS + 0.33% CMC	8.7 ± 0.0cd	12.1 ± 0.2a	14.7 ± 0.6abcd	17.7 ± 0.5a
ACPS + 0.66% CMC	10.1 ± 0.1ab	13.1 ± 0.9a	15.5 ± 0.3ab	18.6 ± 0.9a
ACPS + 1.0% CMC	9.2 ± 0.2bc	13.4 ± 0.8a	15.3 ± 0.1abc	17.8 ± 0.0a

*Means followed by the same letter in each column for each starch are not significantly different ($p > 0.05$) by Least Significant Differences.

Table 4 Water solubility indices (WSIs) of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	WSI (%) 65°C	WSI (%) 75°C	WSI (%) 85°C	WSI (%) 95°C
PS	1.6 ± 0.3d	4.7 ± 0.5e	7.6 ± 0.2f	14.4 ± 0.4f
PS + 0.33% GG	1.9 ± 0.2cd	5.0 ± 0.1e	8.5 ± 0.8def	15.4 ± 0.2ef
PS + 0.66% GG	2.0 ± 0.4cd	5.3 ± 0.6de	8.3 ± 0.6ef	16.1 ± 0.4de
PS + 1.0% GG	2.3 ± 0.2cd	5.8 ± 0.5de	9.8 ± 0.1cd	16.6 ± 0.2de
PS + 0.33% XG	2.6 ± 0.1cd	7.1 ± 0.7cd	10.3 ± 0.3c	17.8 ± 0.5bc
PS + 0.66% XG	3.0 ± 0.8bc	8.8 ± 0.2bc	10.7 ± 0.3c	16.8 ± 0.3cd
PS + 1.0% XG	4.3 ± 0.9b	10.0 ± 0.5b	12.7 ± 0.9b	19.5 ± 0.2a
PS + 0.33% LBG	2.3 ± 0.2cd	5.1 ± 0.0de	8.1 ± 0.1ef	15.8 ± 0.1de
PS + 0.66% LBG	2.3 ± 0.1cd	5.5 ± 0.3de	8.0 ± 0.5f	15.7 ± 0.5def
PS + 1.0% LBG	2.4 ± 0.1cd	4.8 ± 0.1e	8.9 ± 0.6cde	17.9 ± 0.9bc
PS + 0.33% CMC	3.1 ± 0.4bc	7.8 ± 0.7c	10.0 ± 1.3cd	16.0 ± 0.8de
PS + 0.66% CMC	4.3 ± 1.8b	10.3 ± 1.4b	12.9 ± 0.7b	18.1 ± 0.2bc
PS + 1.0% CMC	6.2 ± 0.1a	13.4 ± 2.1a	16.0 ± 0.9a	18.7 ± 0.1ab
ACPS	13.3 ± 0.8cde	16.5 ± 0.1b	19.3 ± 0.9cde	25.4 ± 0.5a
ACPS + 0.33% GG	13.1 ± 0.2de	16.6 ± 0.2b	19.7 ± 0.0bcd	24.2 ± 0.6a
ACPS + 0.66% GG	13.0 ± 0.6de	17.6 ± 0.6b	20.6 ± 0.1bc	22.2 ± 0.6a
ACPS + 1.0% GG	13.1 ± 1.2cde	17.1 ± 0.4b	21.0 ± 0.1b	23.6 ± 0.6a
ACPS + 0.33% XG	13.7 ± 0.5bcd	17.5 ± 1.0b	19.3 ± 0.1bcd	25.8 ± 0.2a
ACPS + 0.66% XG	14.9 ± 0.9ab	19.8 ± 0.8a	20.3 ± 0.3bc	25.6 ± 0.8a
ACPS + 1.0% XG	12.0 ± 1.0ef	16.5 ± 0.bf	18.5 ± 0.7de	23.8 ± 0.6a
ACPS + 0.33% LBG	9.5 ± 0.3g	13.0 ± 0.c	17.5 ± 0.7e	24.9 ± 0.7a
ACPS + 0.66% LBG	10.2 ± 0.1g	13.5 ± 0.1c	18.3 ± 0.1de	24.8 ± 0.6a
ACPS + 1.0% LBG	10.6 ± 1.0fg	14.6 ± 0.3c	19.1 ± 0.5cde	24.0 ± 0.7a
ACPS + 0.33% CMC	13.5 ± 0.2bcd	17.7 ± 0.0b	20.4 ± 0.9bc	25.6 ± 0.7a
ACPS + 0.66% CMC	14.6 ± 0.7abc	19.4 ± 1.3a	23.4 ± 1.9a	27.3 ± 1.0a
ACPS + 1.0% CMC	15.8 ± 0.1a	20.8 ± 0.3a	23.3± 0.3a	25.9 ± 0.3a

*Means followed by the same letter in each column for each starch are not significantly different ($p > 0.05$) by Least Significant Differences.

starch (SP = 7.8%; p> 0.05) or a low degree of substitution, acetylated corn starch (SP = 7.8%; p > 0.05). At 85°C, the swelling powers of PS with 1% XG or 0.66% CMC were comparable to those of a medium degree of substitution, cross-linked waxy corn starch (SP = 15.0%; p > 0.05). At 95°C, the swelling powers of PS and 0.66 or 1% GG, PS and 0.33% XG, and PS and 0.66% LBG were comparable to those of a low degree of substitution, acetylated corn starch (SP = 17.8%; p > 0.05).

Freeze-thaw stabilities of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC)

The ability of a starch gel to withstand freezing and thawing without releasing water (syneresis) is a function of the degree of starch retrogradation. Freeze-thaw stabilities of PS, ACPS and combinations of PS or ACPS and GG, XG, LBG or CMC are presented in Table 5. Generally, combinations of PS or ACPS with hydrocolloids exhibited lower levels of syneresis than did PS or ACPS, respectively. ACPS and combinations of ACPS with hydrocolloids exhibited higher levels of syneresis than did PS or corresponding combinations of PS with hydrocolloids, due to the lower concentration of starch in ACPS compared to PS.

Others have investigated the stabilization of starch gels to freezing and thawing using hydrocolloids, e.g. tapioca starch and xanthan gum (Pongsawatmanit and Srijunthongsiri 2008), sweet potato starch and alginate, GG or XG (Lee et al 2002) and rice or wheat starch and LBG or yellow mustard mucilage (Liu et al 2006). Molecular interactions between the hydrocolloid and leached amylose may reduce retrogradation and lower

Table 5 Freeze-thaw stabilities (% syneresis) of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	Freeze-Thaw Cycles				
	1	2	3	4	5
PS	26.6 ± 2.1ab	29.1 ± 2.0ab	31.3 ± 2.0a	32.5 ± 2.0bc	33.0 ± 2.2abcd
PS + 0.33% GG	24.1 ± 0.0cd	24.7 ± 0.0cd	26.9 ± 0.0cd	30.1 ± 0.0de	30.6 ± 0.3bcde
PS + 0.66% GG	23.5 ± 0.7cd	24.1 ± 0.7cd	26.3 ± 0.7cd	29.5 ± 0.5e	30.0 ± 0.6cde
PS + 1.0% GG	20.2 ± 1.0f	22.8 ± 1.0f	25.1 ± 1.0f	26.2 ± 1.2g	26.7 ± 1.1e
PS + 0.33% XG	26.5 ± 0.3ab	29.0 ± 0.4a	31.2 ± 0.3a	33.7 ± 1.8ab	35.1 ± 1.6ab
PS + 0.66% XG	26.4 ± 0.2ab	28.9 ± 0.1a	31.1 ± 0.6ab	32.4 ± 0.1bcd	37.8 ± 1.0a
PS + 1.0% XG	20.8 ± 0.3ef	23.2 ± 0.2b	25.4 ± 0.2ef	27.2 ± 0.5f	27.9 ± 0.6be
PS + 0.33% LBG	27.7 ± 1.5a	30.2 ± 0.8a	32.4 ± 1.3a	35.5 ± 1.2a	36.2 ± 1.0a
PS + 0.66% LBG	26.8 ± 0.7a	29.3 ± 0.3a	31.5 ± 0.1aa	33.4 ± 0.1ab	34.7 ± 0.4abc
PS + 1.0% LBG	28.5 ± 1.8a	30.9 ± 2.0b	33.1 ± 2.1a	34.9 ± 1.4a	36.3 ± 1.9a
PS + 0.33% CMC	22.1 ± 0.2def	24.6 ± 0.3b	26.8 ± 0.5def	28.8 ± 0.6ef	29.4 ± 0.4de
PS + 0.66% CMC	24.4 ± 0.3bc	26.8 ± 0.2ab	29.0 ± 0.6bc	30.6 ± 0.2cde	31.3 ± 0.0bcde
PS + 1.0% CMC	22.7 ± 0.9cde	25.1 ± 1.0b	27.4 ± 0.7cde	29.2 ± 0.5e	29.8 ± 0.8de
ACPS	32.9 ± 0.4bc	34.4 ± 0.4ab	36.6 ± 0.3ab	39.8 ± 0.4bcd	40.3 ± 0.8bcd
ACPS + 0.33% GG	30.9 ± 0.3cd	32.4 ± 0.1bc	34.6 ± 0.6bc	37.9 ± 0.3cd	38.4 ± 0.7cdef
ACPS + 0.66% GG	30.3 ± 0.3cd	31.8 ± 0.7bc	34.0 ± 3.0bc	37.2 ± 3.2cd	37.8 ± 3.2cde
ACPS + 1.0% GG	29.1 ± 0.5f	30.6 ± 0.8e	32.8 ± 0.9e	36.1 ± 1.1f	36.7 ± 1.1g
ACPS + 0.33% XG	33.9 ± 0.2ab	35.4 ± 0.2a	37.6 ± 0.2a	41.3 ± 0.6ab	42.7 ± 1.8ab
ACPS + 0.66% XG	34.0 ± 0.5ab	35.5 ± 0.4a	37.6 ± 0.5a	41.0 ± 0.4ab	42.2 ± 0.2ab
ACPS + 1.0% XG	30.6 ± 0.9de	32.0 ± 1.2cd	34.2 ± 2.1cd	38.0 ± 2.5de	38.7 ± 2.8def
ACPS + 0.33% LBG	34.7 ± 0.8ab	36.1 ± 0.7a	38.4 ± 0.8a	42.0 ± 0.6a	43.0 ± 0.3a
ACPS + 0.66% LBG	34.8 ± 0.9a	36.3 ± 0.8a	38.5 ± 0.5a	42.2 ± 0.9a	42.8 ± 0.8a
ACPS + 1.0% LBG	33.1 ± 0.9abc	34.5 ± 0.9ab	36.7 ± 0.7ab	40.3 ± 0.8abc	41.2 ± 0.9abc
ACPS + 0.33% CMC	28.6 ± 0.1f	30.0 ± 0.1e	32.2 ± 0.8e	36.0 ± 0.1ef	36.8 ± 0.2efg
ACPS + 0.66% CMC	29.1 ± 0.3ef	30.5 ± 0.3de	32.7 ± 0.6de	36.0 ± 0.3ef	36.5 ± 0.7fg
ACPS + 1.0% CMC	31.5 ± 0.6cd	32.9 ± 0.4bc	35.1 ± 0.6bc	38.8 ± 1.2cd	39.3 ± 1.1cd

*Means followed by the same letter in each column for each starch are not significantly different ($p > 0.05$) by Least Significant Differences.

syneresis of starch gels (Christianson et al 1981; Shi and BeMiller 2002). Freeze-thaw stabilities of PS with hydrocolloids were comparable to those of a cross-linked normal rice starch (% syneresis ranging from 20-30% for 1-5 freeze-thaw cycles) (Liu et al 1999).

Shear stabilities of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC)

Shear stability indicates the susceptibility of a starch paste to mechanical breakdown (due to shear) after the slurry has undergone gelatinization. Shear stabilities of gels from of PS, ACPS, and combinations of PS or ACPS and GG, XG, LBG or CMC are presented in Table 6. Generally, the combinations of PS or ACPS with hydrocolloids exhibited higher shear stabilities, or shear stabilities that were not significantly different, than those of PS or ACPS. In most instances, the shear stabilities of combinations of PS and hydrocolloids were not significantly different than those of corresponding combinations of ACPS and hydrocolloids. The most noteworthy exceptions were the shear stabilities of PS or ACPS and GG and the shear stabilities of PS or ACPS and 1% CMC. The addition of GG to PS increased the shear stability of PS from 80% to 90-91%, whereas the addition of GG to ACPS did not have a significant effect on shear stability. The addition of 1% CMC to PS raised the shear stability of PS from 80% to 88%, whereas the addition of 0.66 or 1% CMC to ACPS lowered the shear stability from 85% to 80 and 72%, respectively. This may be attributed to interference of protein and fibre from shear stabilizing starch-hydrocolloid interactions in the presence of CMC. In all cases, the viscosity of the starch or combination of starch and hydrocolloid did not recover to the pre-shear value since all shear stabilities were less than 100%. PS with GG, PS with LBG

Table 6 Shear stabilities (%) of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	Shear stability
PS	80 ± 2ef
PS + 0.33% GG	91 ± 2a
PS + 0.66% GG	90 ± 2a
PS + 1.0% GG	91 ± 2a
PS + 0.33% XG	79 ± 1g
PS + 0.66% XG	80 ± 1fg
PS + 1.0% XG	80 ± 1fg
PS + 0.33% LBG	85 ± 2d
PS + 0.66% LBG	87 ± 1cd
PS + 1.0% LBG	90 ± 1a
PS + 0.33% CMC	81 ± 1aefg
PS + 0.66% CMC	83 ± 1e
PS + 1.0% CMC	88 ± 1bc
ACPS	85 ± 1abc
ACPS + 0.33% GG	88 ± 1a
ACPS + 0.66% GG	89 ± 1a
ACPS + 1.0% GG	90 ± 1a
ACPS + 0.33% XG	87 ± 1a
ACPS + 0.66% XG	87 ± 1a
ACPS + 1.0% XG	87 ± 1a
ACPS + 0.33% LBG	86 ± 4a
ACPS + 0.66% LBG	84 ± 1bc
ACPS + 1.0% LBG	84 ± 1bc
ACPS + 0.33% CMC	84 ± 1bc
ACPS + 0.66% CMC	80 ± 1d
ACPS + 1.0% CMC	72 ± 1e

*Means followed by the same letter for each starch are not significantly different ($p > 0.05$) by Least Significant Differences.

and ACPS with GG exhibited higher recoveries, likely due to hydrocolloid molecules entangling with leached amylose, increasing shear stability (Mandala et al 2004). Tye (1988) reported that corn starch with 0.2% kappa-carrageenan did not recover to its pre-shear viscosity, but that corn starch plus 0.2% or 0.5% iota-carrageenan or 0.5% kappa-carrageenan did recover to its pre-shear value. The shear stabilities of PS with GG, PS with 1% LBG and ACPS with 1% GG were comparable to those of a medium degree of substitution, cross-linked waxy corn starch (92%; $P > 0.05$), a low degree of substitution, acetylated corn starch (91%; $p > 0.05$) and a high degree of substitution, cross-linked waxy corn starch (91%; $p > 0.05$). The shear stability of PS plus 1% CMC, ACPS plus 0.33% GG and ACPS plus XG were comparable to shear stabilities of a low degree of substitution, cross-linked corn starch (88%; $p > 0.05$).

Water binding capacities and oil absorption capacities of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC)

Water binding capacity is the amount of water that a starch can retain at room temperature without gelatinization and is an indication of the ability of the starch to form hydrogen bonds with water. Water binding capacities (WBCs) and oil absorption capacities (OACs) of PS, ACPS and combinations of PS or ACPS and GG, XG, LBG or CMC are presented in Table 7. Generally, combinations of PS and hydrocolloids exhibited WBCs that were not significantly different than that of PS, with the exceptions of PS plus 1% GG or 0.66% XG which increased the WBC of PS, and PS plus 0.33 or 0.66% LBG or 0.33. 0.66 or 1.0% CMC, which lowered the WBC. All combinations of ACPS and

Table 7 Water binding capacities (WBCs) and oil absorption capacities (OACs) of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	WBC (%)	OAC (%)
PS	102.2 ± 0.6c	8.2 ± 0.1a
PS + 0.33% GG	101.1 ± 0.3de	8.1 ± 0.1a
PS + 0.66% GG	103.6 ± 0.9c	8.0 ± 0.1a
PS + 1.0% GG	108.4 ± 0.4b	8.0 ± 0.0a
PS + 0.33% XG	101.3 ± 1.2c	8.2 ± 0.1a
PS + 0.66% XG	106.8 ± 0.8b	8.2 ± 0.0a
PS + 1.0% XG	111.4 ± 3.1a	8.3 ± 0.1a
PS + 0.33% LBG	97.9 ± 0.4de	8.1 ± 0.1a
PS + 0.66% LBG	98.2 ± 0.2d	8.1 ± 0.0a
PS + 1.0% LBG	101.1 ± 1.5c	8.1 ± 0.1a
PS + 0.33% CMC	95.2 ± 0.3e	8.2 ± 0.1a
PS + 0.66% CMC	96.6 ± 0.8de	8.2 ± 0.0a
PS + 1.0% CMC	98.1 ± 0.4d	8.2 ± 0.0a
ACPS	92.0 ± 0.3h	8.3 ± 0.0a
ACPS + 0.33% GG	104.5 ± 2.1bcde	8.1 ± 0.3a
ACPS + 0.66% GG	103.0 ± 1.6cdef	8.0 ± 0.1a
ACPS + 1.0% GG	105.0 ± 2.1bcd	8.0 ± 0.1a
ACPS + 0.33% XG	105.9 ± 1.3abc	8.2 ± 0.0a
ACPS + 0.66% XG	107.7 ± 0.4ab	8.2 ± 0.0a
ACPS + 1.0% XG	110.4 ± 1.9a	8.1 ± 0.1a
ACPS + 0.33% LBG	100.1 ± 0.3efg	8.3 ± 0.0a
ACPS + 0.66% LBG	100.6 ± 0.9defg	8.2 ± 0.0a
ACPS + 1.0% LBG	103.9 ± 2.4abc	8.1 ± 0.0a
ACPS + 0.33% CMC	99.1 ± 2.1fg	8.2 ± 0.1a
ACPS + 0.66% CMC	98.8 ± 2.7fg	8.2 ± 0.0a
ACPS + 1.0% CMC	97.7 ± 2.3g	8.2 ± 0.0a

*Means followed by the same letter in each column for each starch are not significantly different ($p > 0.05$) by Least Significant Differences.

hydrocolloids exhibited higher WBCs than did ACPS. Although CMC easily solubilizes in water at room temperature, PS with CMC exhibited lower WBCs than did PS, possibly by blocking the water binding sites of PS and limiting hydrogen bond formation between starch molecules and water.

Oil absorption capacity (OAC) is a measure of the amount of oil that a starch or blend of starch and hydrocolloid can absorb. PS and ACPS exhibited OACs that were not significantly different than PS or ACPS, and none of the hydrocolloids had an effect on the OAC of PS or ACPS.

Resistant starch concentrations of pea starch (PS), air-classified pea starch (ACPS), and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC)

Resistant starch (RS) is not hydrolyzed during digestion in the gastrointestinal tract of a healthy human (Englyst et al 1992). The resistant starch concentrations in PS, ACPS and combinations of PS or ACPS and GG, XG, LBG or CMC are presented in Table 8. The addition of a hydrocolloid did not have a marked effect on the RS concentration in PS or ACPS. The addition of 0.66 or 1.0% of GG did increase slightly the RS concentration in PS, whereas the addition of 0.66 or 1.0% of CMC had the opposite effect. The addition of GG, XG or LBG increased slightly the RS concentration in ACPS, whereby the addition of CMC had the opposite effect. PS exhibited a higher concentration of RS than did ACPS (6.6 vs. 3.4%). Gularte and Rosell (2011) reported that combinations of corn starch and hydrocolloids (methoxylated pectin, GG, CMC, XG or hydroxypropylmethyl cellulose) exhibited higher rapidly digestible starch concentrations and no change in RS

Table 8 Resistant starch concentrations of pea starch (PS), air-classified pea starch (ACPS) and PS or ACPS and guar gum (GG), xanthan gum (XG), locust bean gum (LBG) or carboxymethyl cellulose (CMC).*

	Resistant starch (%)
PS	6.6 ± 0.4cd
PS + 0.33% GG	7.4 ± 0.2abc
PS + 0.66% GG	7.9 ± 0.5a
PS + 1.0% GG	7.8 ± 0.8ab
PS + 0.33% XG	6.3 ± 0.1de
PS + 0.66% XG	6.0 ± 0.0de
PS + 1.0% XG	6.1 ± 0.1de
PS + 0.33% LBG	7.1 ± 0.3bc
PS + 0.66% LBG	7.4 ± 0.6abc
PS + 1.0% LBG	7.0 ± 0.2c
PS + 0.33% CMC	5.5 ± 0.1de
PS + 0.66% CMC	5.5 ± 0.3ef
PS + 1.0% CMC	5.2 ± 0.1f
ACPS	3.4 ± 0.1e
ACPS + 0.33% GG	3.7 ± 0.2d
ACPS + 0.66% GG	3.9 ± 0.1d
ACPS + 1.0% GG	4.3 ± 0.1c
ACPS + 0.33% XG	3.4 ± 0.1d
ACPS + 0.66% XG	3.7 ± 0.0d
ACPS + 1.0% XG	3.8 ± 0.1d
ACPS + 0.33% LBG	4.3 ± 0.2c
ACPS + 0.66% LBG	6.7 ± 0.1b
ACPS + 1.0% LBG	7.2 ± 0.1a
ACPS + 0.33% CMC	2.8 ± 0.2f
ACPS + 0.66% CMC	2.6 ± 0.0f
ACPS + 1.0% CMC	2.9 ± 0.4f

*Means followed by the same letter for each starch are not significantly different ($p > 0.05$) by Least Significant Differences.

concentrations for corn starch with methoxylated pectin, GG or CMC, and lower RS concentrations for corn starch with XG or hydroxypropylmethyl cellulose. Additionally, Gularte and Rosell (2011) reported that potato starch plus methoxylated pectin, GG, XG or CMC exhibited higher RS values than did potato starch. The RS concentration was lower for potato starch plus hydroxypropylmethyl cellulose than for potato starch. Differences between these results and the results from the current study may be attributed to differences in methodology. In the current study, the determination of RS concentration was performed on combinations of ungelatinized PS or ACPS and hydrocolloids, whereas in the Gularte and Rosell (2011) study, RS was determined in freeze-dried, gelatinized samples. Typically, gelatinization of starch samples lowers resistant starch concentration (Emami et al 2010).

SUMMARY AND CONCLUSIONS

The thermal properties, pasting properties, swelling powers, water solubility indices, freeze-thaw stabilities, shear stabilities, water binding capacities, oil absorption capacities and resistant starch concentrations of PS, ACPS and combinations of PS or ACPS and 0.33, 0.66 or 1.0% of GG, XG, LBG or CMC were investigated. Generally, the effects of the hydrocolloids on the functionality of PS and ACPS were slight. For some functional properties, differences between PS and ACPS, and between corresponding combinations of PS or ACPS and hydrocolloids, reflected the lower concentration of starch and the higher concentration of protein and fibre in ACPS. It was concluded that certain combinations of pea starch and hydrocolloids may exhibit potentially valuable functional properties for food and non-food applications without a requirement for

chemical modification, as some combinations exhibited functionalities comparable to those of chemically-modified starches. However, combinations of PS or ACPS and hydrocolloids were not comparable to any chemically-modified starch with respect to all of the functionalities examined.

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